THE HYDROGEN ION CONCENTRATION OF THE MIXED SALIVA CONSIDERED AS AN INDEX OF FATIGUE AND OF EMOTIONAL EXCITATION, AND APPLIED TO A STUDY OF THE METABOLIC ETIOLOGY OF STAMMERING[1]

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Psychology today is finding in reflex arcs and reaction patterns definite foundation-stones such as chemistry obtained in the concepts of atom and molecule. Behind the simple reflex, however, as well as behind the more complex performance, we find as prime determinants the amount of energy at the disposal of the individual and his degree of excitability. Energy and excitability, mutual interdependents to a considerable extent, condition both quality and quantity of performance, even when the latter appears to the unanalytical to be determined solely by motivation. And what is "motivation", that mysterious "mover" which the dualists call "soul", manifesting itself in hope and fear, desire and aversion, love and hate,—a labyrinthine complexus of interacting instincts, emotions, apperceptive residua, and bodily tone? May it not be considered as the resultant harmony or discord of the play, energetic or feeble, anabolic or catabolic, of metabolism upon anatomical structure?—harmony or "normality", if it blends with the environment; discord or "abnormality," if the pitch be too high or too low?

I have spoken of motivation as the resultant of the play of physiological processes. I do not insist upon that as a final mechanistic definition. For the purposes of this study I am quite willing to accept as a working hypothesis that the physiological processes are the result of psychical stimuli. That a misbehaving liver may spoil one's temper, or that a chronic ill-temper may affect the liver, may either or both be tritely true. What at this time I wish to call especial attention to is the fact that even motivation, that most psychical of psychological processes, is correlated with or parallels metabolism. Correlation of behavior with bodily tone is obvious in any performance. Efficiency, intellect, intelligence, all are being measured today by means of standardized tests, as a result of which the psychological examiner grades the performer on a relative scale, more or less accurately,—the degree of accuracy depending primarily upon the psychological diagnostic ability of the examiner. It is patent even here, however, that bodily tone, energy at the disposal of the performer, excitability, and general motivational attitude of the subject determine to some extent the amount of product he will turn out in a unit of time, his ability to put to use knowledge already acquired, his ability to solve what

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is for him a new problem.[2] In every instance the physiological factor is evident. We may cling to the subterfuge of psychophysical parallelism, admit no interaction between the mental and the physical, regard them as such absolutely distinct categories that nothing of either can stand in a causal relation to anything in the other. But we must admit that the parallelism is frequently so close that between the lines there is scarce the width of Omar's false from true dividing hair.

Avoiding anything of a controversial nature, however, it is sufficient to note that the physiological may serve as an index of the psychological. This was pointed out by Bell in his "Anatomy and Philosophy of Expression," and the thesis was subsequently developed more scientifically by Darwin in his study of "Expression of the Emotions in Man and Animals." It is, in fact, the initial premise of the psychological examiner who observes a performance and interprets it in terms of thought, intellect, intelligence, etc. And if psychologists today are able thus to diagnose the mental conditions by observing gross bodily movements, what *finesse* they would gain by the employment of tests indicating quickly and accurately the metabolic status, degree of emotional stress, and energy at the disposal of the individual, irrespective of any attempts at malingering or excessive performance on the part of the subject, manifesting themselves in overt acts difficult of interpretation by a purely psychological procedure. Such indices, obviously, will have to be developed along the lines of the science which is employed for purposes of metabolic diagnosis, *i. e.*, of physiological chemistry. Physiology is the connecting link between psychology and chemistry. We need not go so far as to assert that psychology is a "refined physiology." We need simply to recognize the fact that the physiological parallels the psychological and is indicated by the chemistry of the individual.

In this connection Pawlow[3] merits special mention as having first reported the effect of purely psychical stimuli upon the digestive glands resulting in chemical differentiation of secretion. Cannon's work on the adrenals is a chemical study of the great emotives: pain, hunger, fear, and rage.[4] Crile's interesting and important attempt to portray man as an "adaptive mechanism"[5] would give to human behavior the foundation of a chemically activated kinetic system, consisting of brain, thyroid, adrenals, liver and muscles. Sajous,[6] Laignel-Lavastine,[7] and other investigators of the internal secretions have proved that the metabolism of the ductless glands is the chief etiological factor in many "mental" conditions.

Meanwhile, particularly along the lines of colorimetry and nephelometry, physiological chemistry has been rapidly developing an ever more delicate and accurate technique for the detection and determination of the products of metabolism. This is especially notable in the field of hydrogen ion determination, thanks largely to the work of Sørenson Palmer and Henderson, Clark and Lubs, and Cullen and Van Slyke. The time

[2]Definitions respectively of efficiency, intellect and intelligence, adapted from Witmer, Reference Book in Clinical Psychology and for Diagnostic Teaching, *Psychological Clinic*, May 15, 1919.

[3]Pawlow, J. P., The Work of the Digestive Glands. Trans. by W. H. Thompson. London, 1902.

[4]Cannon, W. B., Bodily Changes in Pain, Hunger, Fear and Rage. New York, 1915.

[5]Crile, G. W., Man—An Adaptive Mechanism. N. Y., 1916.

[6]Sajous, C. E. de M., The Internal Secretions and the Principles of Medicine. Phila., 1903.

[7]Laignel-Lavastine, M., The Internal Secretions and the Nervous System. New York and Washington, 1919.

is ripe for the application of the exact methods of chemical science to the problems of metabolism conditioning (or indicating) mental states. A psychological chemistry is due, from which may ultimately be developed a chemical psychology.

The material to be employed for chemical analysis, correlated with mental diagnosis, obtainable from a living human, may be the blood, urine, faeces, gastric juice, or saliva. As a means of investigating the metabolism of an individual the blood appears most admirable, in that it is itself virtually living tissue of the organism and carries the secretions, hormones, end-products of digestion, etc. Unfortunately, the popular fear of bleeding would no doubt militate against the usefulness of blood-tests as routine clinical methods of psychological diagnosis, and the fear reaction *per se* might so alter the blood as to render it of no diagnostic value with regard to the motivational or emotional *status quo*. The urine is accessible more readily and in greater quantity than is the blood. But it represents the waste-products taken from the blood by the kidneys and, in many cases, altered in transit. As such it is not a direct index of immediate metabolic condition such as manifests itself in more or less transient mental or psychical states. (Of course the general metabolic condition of the body may be frequently inferred from these waste-products.) The faeces, apart from the fact that they obviously would never become widely-employed clinical material, are contaminated by undigested food, and would furnish no index of material assimilated and thus affecting the economy, without an accurate preliminary analysis of the food ingested. Nor would they be of value as indices of transient emotional states, etc. To the gastric juice and stomach-contents objections may be raised similar to those advanced with respect to the faeces.

There remains the saliva. This fluid is constantly being secreted, swallowed, and passed through the physiological cycle. It may be readily collected for examination at all times and places. It may be regarded practically as transformed protoplasm of the secreting cell, with admixture of salts and other substances virtually dialyzed from the blood, and affected to a greater or lesser degree by the conditions obtaining in the oral cavity and by the constituents of the alveolar air. The glands of secretion have abundant neural connections with both the cranial and the sympathetic nervous systems. Thus of the three principal sets of salivary glands—sublingual, submaxillary and parotid—each one is innervated by both cranial and sympathetic nerves. The chorda tympani connects with the submaxillary and sublingual glands. The auriculo-temporal branch of the trifacial nerve supplies the parotid. As to the sympathetic fibres, to quote Fischer,[8] they "are derived in the

[8]Fischer, M. H., The Physiology of Alimentation. New York, 1907.

main from the second, third and fourth thoracic nerves, which, after passing into the sympathetic chain, ascend to the superior cervical ganglion, from which nerve fibres.....are given off that, after following the external carotid artery, are finally distributed to the various salivary glands." The amount and composition of the secretion of a given gland vary according to the nerve stimulated, as noted particularly by Heidenhain and by Langley. In his everyday experience the clinical psychologist observes the drooling of the idiot, and frequently the dry mouth of fear, the latter being especially exemplified by the well-known Chinese "ordeal of rice." Thus the saliva suggests itself as a possible index of metabolic conditions manifesting themselves in mental or emotional states.

That the salivary composition and reaction vary in health and disease has been reported by various investigators. Almost a century ago (1835) Donne noted that the saliva was acid to litmus in certain diseases, including encephalitis, whereas he regarded it as normally alkaline.[9] Today Kirk is the foremost protagonist of the diagnostic value of the saliva, especially with reference to metabolic factors in the etiology of dental caries,[10] and his kindly advice has been a distinct aid in the present research.

When, early in 1920, the Directors of the Psychological Laboratory and Clinic of this university asked the writer as to the feasibility of employing the salivary reaction as an adjunct in clinical psychological diagnosis, his first step was a survey of the biochemical literature bearing upon the problem.[11] He found that while many, and contradictory, findings had been reported as to the alkalinity and acidity of the mixed saliva under various conditions, much of the work had been of the crude litmus paper type. The more carefully conducted examinations had been made principally by titrational quantitative methods, in which field the work of Gies has been most intensive.[12] In titrational quantitative determinations the degree of acidity or alkalinity reported expresses conversely the quantity of alkali or acid required to be added to a definite quantity of the "unknown" (in this instance the saliva) in order to render the resultant solution neutral. The saliva, however, is an amphoteric liquid, *i. e.*, within certain limits it will act as an alkali to neutralize acids or as an acid to neutralize alkalis. Consequently titrational methods give no direct determination of the *status quo* of the intensity factor of the "acidity," which arises from the quantity of ionic hydrogen present in the solution. More recent chemical research in various biological fields, however, has resulted in the discovery that in the majority of instances the hydrogen ion concentration is a greater determinant of certain life phenomena than is titratable acidity. That is, the quantity of ionic hydrogen present in a given volume of the solution under examination is frequently a more important biological factor than is the quantity of hydrogen which may be replaced in the course of titration with an alkali.

It may not be out of place to note here that a hydrogen ion is an atom of hydrogen bearing a single positive electric charge; *i. e.*, it is a univalent anion. A hydroxyl ion (OH^-) is a chemical radical bearing a single negative

[9]Donne, A., *Arch. génér. de Med.*, May 1835.

[10]Kirk, E. C., *The Dental Review*, May 1903.

[11]For a review of the biochemical literature, see Starr, H. E., Biochemical Studies of Human Mixed Saliva. I.

[12]*Op cit.*

electric charge; *i. e.*, it is a univalent cation. When a substance is dissolved, it dissociates to a greater or lesser extent into anions and cations. Thus in the case of water (H_2O) itself there is a certain amount of dissociation, as expressed by the equation: $HOH \rightleftarrows H^+ + OH^-$. The lines of the equality sign are arrow-tipped in opposite directions to indicate that the reaction is reversible. The ratio of the product of the concentrations of the anions and cations to the concentrations of the undissociated molecular portion is a constant for a given salt in a given solvent at a given temperature. Thus, if

(A) = concentration of anion,
(C) = concentration of cation,
(AC) = concentration of undissociated molecules,
K = a constant,

then $\frac{(A) \times (C)}{(AC)} = K.$

In pure water, hydrogen furnishes the anion (H^+) and hydroxyl the cation (OH^-), while HOH is the formula of the undissociated molecule, hence

$$\frac{(H^+) \times (OH^-)}{(HOH)} = K.$$

Pure water, however, is so slightly dissociated [*i. e.*, (HOH) is so extremely great in proportion to $(H^+) \times (OH^-)$] that for all practical purposes we may discard the denominator, substitute another constant (k_w), and write our equation as:

$(H^+) \times (OH^-) = k_w$. Here ($H^+$) represents the quantity of ionic hydrogen and (OH^-) the quantity of hydroxyl ions. By electrometric determinations it has been found that for perfectly pure neutral water at 21° C. the value of k_w is 10^{-14}; and as in a neutral solution there must be an equal quantity of hydrogen ions and of hydroxyl ions, it follows that 1 liter of pure neutral water contains 10^{-7} grams of each kind of ions. Consequently if, at 21° C., a solution contains less than 10^{-7} gms. of H ions per liter, it contains more than 10^{-7} gms. of OH ions per liter, and is therefore "alkaline." Conversely, if it contains more than 10^{-7} gms. of H ions per liter, it must contain less than 10^{-7} gms. of OH ions per liter, and is therefore "acid." Or, perhaps more simply, if a solution contains more H^+ ions than OH^- ions, it is called "acid"; if it contains more OH ions than H ions, it is called "alkaline." But whether acid or alkaline it must contain some H ions, and consequently we may scale all solutions in terms of greater or lesser hydrogen ion concentration. As Sørenson pointed out, $\log_{10}\frac{1}{(H)}$ may be used to express a given hydrogen ion (H ion, or hydrion) concentration in lieu of (H^+). He suggested for this the symbol P_H^+. This Sørenson negative logarithmic notation, as it has been termed, is now quite widely adopted, the symbol having been simplified, however to pH. Thus a H ion concentration of 10^{-7} is written simply as pH 7.00. Or, for example, a solution of acetic acid, containing 6.0 grams of acetic acid per liter, has a H ion concentration of 1.36×10^{-3} which equals $10^{0.133-3}$ or $10^{-2.867}$, and which may be expressed as pH 2.867. Thus $pH = -\log_{10}(H^+)$. Because of the greater simplicity of the Sørenson notation the writer has employed it in the present research. It must be borne in mind throughout that the hydrogen ion concentration varies inversely as to direction with the pH; *i. e.*, a low pH indicates a high H ion concentration, and a high pH indicates a low H ion concentration. Consequently when the "salivary pH" is spoken of as increasing, the hydrogen ion concentration of the mixed saliva is decreasing, and conversely.

Prior to engaging in the present research, the writer found it necessary to make a series of "Biochemical Studies of Human Mixed Saliva" in the course of which was developed a technique for the colorimetric determination of the hydrogen ion concentration of the mixed saliva, or "salivary pH." The general procedure is to collect the saliva without the aid of a stimulus (as the chewing of inert substances was found to raise the salivary pH),[13] to make the determination immediately after ejection of the specimen without allowing it to stand or centrifuging it (as each of these measures was found to make for decreased salivary pH),[13] and to employ 1 cubic cm. of the saliva for a determination, which is made by adding dibromothymolsulphonephthalein or phenolsulphonephthalein to the saliva diluted with water of an H ion concentration of pH 6.6—6.7, and comparing the resultant virage with those obtained by similar treatment of standard solutions of known pH.[14]

It is obvious that the actual quantity of ionic hydrogen detected by the colorimetric determination of hydrogen ion concentration is quite small. Thus, there is required but 1 cubic cm. of saliva in the technique employed throughout this investigation. Consequently, if the hydrion concentration of the saliva is reported as 6.00, which means that one liter of the saliva contains 1/1,000,000 gram of ionic hydrogen, there has been actually determined in the one cubic cm. employed 1/1,000,000,000 gram of ionic hydrogen. Similarly, when the hydrogen ion concentration is reported as pH 7.00, it means that there has been determined 1/10,000,000,000 gram of ionic hydrogen in the 1 cubic cm. It may be of interest to note that a solution of pH 6.00 is indicated by a pale yellow color when phenolsulphonephthalein is used, and by a "grass green" when dibromothymolsulphonephthalein is employed; whereas a solution of pH 7.00 displays a distinctly red color with the former and a decided blue with the latter indicator. The color changes in the lower range are better indicated by the latter than by the former; for the higher ranges, the reverse is true.

Having thus an adequate technique, the next step was the determination of the hydrogen ion concentration of 610 specimens of human mixed saliva collected from 228 healthy normal subjects. The 610 specimens included 5 specimens each from 41 individuals; 4 specimens each from 6 individuals; 3 specimens each from 19 individuals; and 2 specimens each from 162 individuals. The range was found to be from pH 5.95 to pH 7.25, with 86.6% of the specimens within the limits of pH 6.55 to pH 7.00 inclusive. The mean was pH 6.78; the median, pH 6.80; and the mode pH 6.80 to pH 6.90 inclusive. The results of this investigation, in terms of relative frequency, are presented in Table 1, and also in Graphs 1 and 2. It was noted that in general, when the salivary pH was 6.60 or less, the individual appeared fatigued or deficient in the amount of energy at his disposal; when the salivary pH was about 7.00 the individual appeared to have an abundance of energy at his disposal.[15]

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[13] *Op. cit.*

[14] *Op. cit.*

[15] *Op. cit.*

Table 1. The Hydrogen Ion Concentration of the Mixed Saliva of Normal Healthy Individuals, in Terms of Relative Frequency.[16]

Hydrogen ion concentration of the mixed saliva	Relative frequency
pH	%
5.95	0.2
6.00	0.5
6.05	—
6.10	0.3
6.15	0.2
6.20	0.3
6.25	0.3
6.30	0.2
6.35	0.5
6.40	1.0
6.45	1.6
6.50	3.0
6.55	4.9
6.60	6.7
6.65	6.4
6.70	9.2
6.75	9.8
6.80	11.6
6.85	12.1
6.90	11.5
6.95	7.9
7.00	6.4
7.05	1.5
7.10	1.3
7.15	1.3
7.20	0.8
7.25	0.5

Following the determination of the normal physiological range of salivary hydrion concentration, experiments were made to ascertain whether or not a diurnal rhythm might be found.[17] Twenty-two salivary pH determinations were made at intervals during a day of inactivity and total abstinence from food, 22

[16]Adapted from Starr, Biochemical Studies of Human Mixed Saliva. The values of salivary pH reported are probably somewhat higher than the actual values obtaining in the oral cavity, inasmuch as in the method employed it was impossible to avoid a slight loss of CO_2 during the determinations with concomitant increase in pH of from 0.05 to 0.15 pH. This, of course, does not affect comparisons made between the values of pH found or the conclusions drawn therefrom.

[17]*Op. cit.*, II.

on a day of inactivity when a mixed diet was ingested, 16 on a day of normal activity and total abstinence from food, 14 on a day of normal activity when a mixed diet was ingested. A tendency toward a rhythm was noted; but the most marked and constant finding was a steady decrease in salivary pH from about 2.00 P. M. until the ingestion of dinner at 6.00 P. M. This result tended to confirm a tentative conclusion drawn during the preliminary investigation of 228 subjects, *viz.*, that the hydrion concentration of the mixed saliva increased when the individual was fatigued or lacked energy. Accordingly a series of 88 determinations[17] of salivary pH were made on 7 individuals during days of normal activity and mixed diet. The findings pointed practically invariably to a steady decrease in salivary pH during the afternoon, *i. e.*, toward the close of the working day when the individual's energy was ebbing and the products of fatigue, the principal of which is carbon dioxide, were accumulating in his tissues and blood.

In the course of the latter investigation, however, it was noted on several occasions that when a subject was emotionally excited his salivary pH increased regardless of the time of day. Thus subject I.G. at 3.00 P. M. had a salivary pH of 6.70; following some fairly strenuous exertion in the pursuit of his work, his salivary pH dropped by 4.00 P. M. to 6.60. At 5.00 P. M., just after the extinguishment of a slight fire at which he had been present, his salivary pH had increased to 7.20. By 5.30 P. M. it had subsided to 6.90, by 6.00 P. M. to 6.70, and by 6.30 P. M. to 6.60. Similarly M. S., having shown a salivary pH of 6.95 at 2.30 P. M., and a decrease to 6.80 at 3.30 P. M., having been angered about 4.15 P. M. by an individual against whom he dared not display his anger, showed at 4.30 P. M. a salivary pH of 7.25, which, as he grew calmer, subsided by 5.00 P. M. to 6.85 and at 5.30 P. M. had dropped to 6.65. Subsequent to these determinations subject I.F.T. one morning became quite angry. His salivary pH had just been found to be 6.75 at 9.00 A. M. At 9.15, when storming about quite angrily, his salivary pH was again determined, and found to have increased to 6.95. After he realized that he had misunderstood certain matters and that there was no real cause for anger, his salivary pH dropped by 9.32 A. M. to 6.80.

As a "check" on the preceding findings, the following experiment was performed. At 10.08 A. M. a 2 cubic cm. specimen of mixed saliva was collected from G.X.T., an adult male subject, known by the experimenter to be somewhat excitable. The pH of the specimen was 6.90. At 10.13 A. M. the subject was given misinformation calculated to anger him. It resulted as anticipated. At 10.28 A. M., at the height of his rage, he was commanded to "spit" which he did unthinkingly and with ve-

hemence. The pH of this specimen was 7.40. Unfortunately, the explanation of the operator, that the whole affair was staged as an experiment, did not result in any immediate calmness on the part of the subject. He left the laboratory in a rage, but returned about 1.00 P. M., when his salivary pH was found to be only 6.75. The results of the experiments upon normal individuals when laboring under emotional excitement [18] will be found tabulated in Table 2.

Table 2. The Increase in Hydrogen Ion Concentration of the Mixed Saliva Concomitant with Emotional Stress, in Normal and Healthy Subjects

Subject	Prior to Excitement Hydrogen ion concentration of the mixed saliva		During Excitement Hydrogen ion concentration of the mixed saliva		After Excitement had subsided Hydrogen ion concentration of the mixed saliva	
	Time	pH	Time	pH	Time	pH
IG	4.00 P. M.	6.60	5.00 P. M.	7.20	6.00 P. M.	6.70
MS	3.30 P. M.	6.80	4.30 P. M.	7.25	5.30 P. M.	6.65
IFT	9.00 A. M.	6.75	9.15 A. M.	6.95	9.32 A. M.	6.80
GXT	10.08 A. M.	6.90	10.28 A. M.	7.40	1.00 P. M.	6.75

Table 2 shows that under emotional stress four healthy normal individuals, whose average initial salivary pH was 6.75, displayed a decrease in hydrion concentration of the mixed saliva resulting in an average salivary pH of 7.20 which dropped, after they became calm, to an average of 6.73. This may not at first sight appear to be a very great change numerically; but it must be remembered that pH is the negative log to the base 10 of the actual hydrogen ion concentration. The *relative* increase is thus seen to be very great.

The writer next turned his attention to the chemical cause of the hydrogen ion concentration of the mixed saliva, with the result that he has found it to be due primarily to carbon dioxide.[19] This finding at once suggested the carbon dioxide content of the alveolar air, and therefore of the venous blood, as of etiological import. Accordingly 34 determinations of salivary pH in the usual manner, and simultaneous determinations of the carbon dioxide content of the alveolar by means of the Fridericia method,[20] were made on seven individuals, with the result that a definite correlation was found to exist between the salivary pH and the carbon dioxide content of the alveolar air,—the greater the former, the less the latter; *i. e.*, in every

[18] Compare with *op. cit.*

[19] In more correct chemical terminology it is due to the ratio $\frac{H_2CO_3}{BHCO_3}$ in which B represents a univalent base, according to the terminology of Van Slyke, and is to be so understood throughout. Cf. *op. cit.*, I.

[20] For detailed explanation of the Fridericia method for the determination of the carbon dioxide content and tension of the alveolar air, see Hawk, P. B., Practical Physiological Chemistry. 7th ed., Phila.

instance the H ion concentration of the mixed saliva was found to vary directly with the carbon dioxide content of the alveolar air.[21]

The correlation between the carbon dioxide content of the alveolar air and that of the saliva, the latter manifesting itself in hydrion concentration, suggested that a thorough ventilation of the lungs might result in decreased hydrion concentration of the saliva, especially inasmuch as Van Slyke[22] has found that the carbon dioxide of the blood may be "blown off" by voluntary deep breathing. Accordingly, the salivary pH of ten subjects was determined; and they were then placed out-of-doors and required to breathe "deeply and vigorously" for 10 min., when their salivary pH was again determined in the usual manner. It was found that in every instance the pH had, at least temporarily, decreased, indicating a decrease in the hydrion concentration of the mixed saliva.

The intimate association found in the course of these investigations between the hydrogen ion concentration and carbon dioxide content of the mixed saliva and the carbon dioxide of the alveolar air, in relation to concomitant states of fatigue and emotional excitement, leads to innumerable problems of relationship between breathing habits, mental and physical states, and all the ramifying sequelae of the hydrogen ion concentration of bodily fluids, respiration, carbon dioxide content of the blood, the functioning of the adrenals, and so on well nigh *ad infinitum*.

These biochemical and psychochemical findings were discussed with Dr. E. B. Twitmyer, Professor of Psychology and Director of the Clinic for Speech Defects of this University. Dr. Twitmyer has noted for many years that a large number of stammerers have very little chest expansion and may be denominated as "sub-breathers." Some—comparatively few—do not show this defect in the regular clinical examination, but are distinctly psychopathic, others are both psychopathic and sub-breathers. Very few indeed do not fit into one or the other of these categories. Still fewer are not remedied by means of corrective measures which he employs, including a definite series of breathing exercises, carefully calculated to increase the stammerer's use of his lungs.

In this connection it will be recalled that Halle,[23] Gutzmann,[24] Ten Cate,[25] Fletcher[26] and others have studied the breathing habits of stam-

[21] *Op. cit.*

[22] Van Slyke, *Jnl. Biol. Chem.*, 1921, 48, 153.

[23] Halle, *Monats. f. Sprachheilkunde*, X, 1900, 225.

[24] Gutzmann, H., *Monats. f. Sprachheilkunde*, 1908, XVIII, 179. Has also written more than 20 other articles along similar lines.

[25] Ten Cate, M. J., *Monats. f. Sprachheilkunde*, 1902, XII, 247 and 321.

[26] Fletcher, J. M., this JOURNAL, 1914, XXV, 201 ff.

merers in various ways, primarily with reference to the effect upon speech of the gross bodily movements of breathing. One chief difficulty has been that each has apparently attempted to make all stammerers fit into some one specific type, and has not recognized the importance of individual differences and the existence of more than one factor in the etiology of the the defect. Investigators of stammering other than those already cited have apparently neglected the physiological factors entirely, and have applied psychological clinical tests and measurements to stammerers, generally with negative findings. Such an approach is, of course, of a totally inadequate nature. It may be of interest to know the degree of visual imagery or of the intelligence of a stammerer, but—if an individual habitually stammers, he is a stammerer and the stammering *per se* is all-sufficient to diagnose him as a stammerer. Following the diagnosis, in a well regulated clinic, comes the prognosis and prescription of treatment. And here is raised the problem of the metabolic etiology of stammering. It is the etiological factors capable of control which are of primary importance. Dr. Twitmyer has found that certain breathing exercises, together with other drill work, result almost invariably in improvement of the general bodily tone and concomitantly of the speech of stammerers for whom he has prescribed them, on the basis of his diagnosis of them as sub-breathers. Accordingly, at his suggestion and with his cooperation, the writer applied the technique and findings already summarized to a specific study of stammerers applying to his clinic for treatment.

The primary purposes of the research were:

1. (*a*) To determine whether or not such stammerers as showed evidence, in physiological and psychological examination, of being sub-breathers were actually overloaded with carbon dioxide, which would be indicated by the hydrogen ion concentration and carbon dioxide content the mixed saliva; and conversely

(*b*) To determine if the hydrogen ion concentration of the mixed saliva, in connection with determinations of its carbon dioxide content, might be employed as a diagnostic and prognostic aid in the recognition of sub-breathers as a type.

2. (*a*) To determine whether or not such stammerers as were distinctly psychopathic, and in consequence probably more or less constantly in a state of emotional stress, would show a characteristically low hydrogen ion concentration of the mixed saliva; and conversely

(*b*) To find out if the hydrogen ion concentration of the mixed saliva might be employed as an index of more or less chronic emotional disturbance.

3. (*a*) To determine whether or not hyper-sensitive or hyper-excitable subjects would give evidence of their excitement upon the application of a normally inadequate stimulus, by decrease in the hydrion concentration of the mixed saliva; and conversely

(*b*) To determine if decrease in salivary hydrion concentration might be employed in general as an index of transient emotional excitement.

In more general terms:

1. To investigate the metabolic etiology of stammering, and

2. To ascertain the degree of usefulness of determinations of the hydrogen ion concentration and concomitant carbon dioxide content of human mixed saliva in psychological examinations.

With these specific purposes in view the following research was conducted.[27]

1. *Are clinically diagnosed sub-breathing stammerers overloaded with carbon dioxide, and may the hydrogen ion concentration, in connection with the carbon dioxide content of the mixed saliva, be employed as an index of sub-breathing?* Fifty-eight subjects applying to the Speech Clinic for treatment and diagnosed as sub-breathers were examined as follows. The subject was seated in a comfortable chair and told to allow a mouthful of saliva to collect in his mouth, without chewing or other stimulation of the salivary glands. At the expiration of 5 min. he was directed to eject the accumulated saliva into a 15 ml. graduated centrifuge tube. The hydrogen ion concentration of the saliva was at once determined as in the preliminary survey of normal individuals previously described, dibromothymolsulphonephthalein being employed as indicator.[28] Subsequent to the determination of the hydrion concentration, the diluted saliva to which the indicator had been added was aerated in an apparatus previously employed in the biochemical investigations,[29] which involved passing the air through a series of Woulfe bottles and Liebig bulbs containing respectively concentrated sulphuric acid, 30 % sodium hydroxide solution, a tube containing fragments of solid sodium hydroxide, and a small flask containing distilled carbon dioxide free water, prior to it (the air) reaching the saliva through which it bubbled, and washing out the free and loosely combined carbon dioxide which was conveyed by suction into N/5 barium hydroxide solution. The aeration was continued for 45 min., resulting in the formation and separation of a white precipitate of barium carbonate in the tube containing the barium hydroxide solution. Great care was taken throughout to prevent any possible admission of air containing carbon dioxide into the apparatus, and consequently the exact quantity of carbon dioxide thus washed out of the saliva and trapped by the barium hydroxide solution could be ascertained by careful titration of the latter before and after aeration.[30] In every instance, before the period of aeration was completed, the virage of the saliva (with indicator) reached

[27]All of the determinations as regards both sub-breathing and psychopathic stammerers were made upon the subjects when they applied to the Speech Clinic for treatment and *before* they had received corrective treatment. The present research is distinctly with reference to the metabolic etiology of stammering, and the diagnostic value of the salivary pH index. A subsequent research will deal with the results of the treatment given the stammerers by Dr. Twitmyer, as indicated by change in hydrion concentration and carbon dioxide content of the mixed saliva.

[28]Starr, H. E., Biochemical Studies of Human Mixed Saliva, I.

[29]*Ibid.*

[30]*Op. cit.*, I.

or passed neutrality (pH 7.00), while the barium hydroxide solution became turbid, indicating the removal of the carbon dioxide from the saliva. The quantities of carbon dioxide trapped by the barium hydroxide and precipitated as barium carbonate need not be reported, inasmuch as in *every* instance, as just noted above, the hydrogen ion concentration was found to be due to the ratio of free to combined carbon dioxide.[31]

Upon the saliva of the 58 subjects mentioned, 200 determinations were made, distributed as follows: 1 determination each on 18 subjects; 2 determinations each on 8 subjects; 5 determinations each on 29 subjects; 7 determinations each on 3 subjects: thus totalling 200 determinations on 58 sub-breathing stammerers. The results are shown in terms of relative frequency in Table 3.

It is evident from the results presented in Table 3, and shown very clearly in Chart 1, that the sub-breathing stammerers in general and in particular are overloaded with carbon dioxide in their saliva far in excess of the normal individual. Thus the mean, mode and median for the salivary pH of the sub-breathers are respectively 6.00, 5.95 to 6.10, and 6.00, whereas for normal individuals they are respectively 6.8, 6.8 to 6.9 and 6.8. Obviously, therefore, the salivary pH in conjunction with determination of carbon dioxide content by aeration may be employed as an aid in the diagnosis of sub-breathing subjects. That in this series of determinations the salivary pH alone could have been so employed without regard to determination of carbon dioxide content, inasmuch as the latter was always the chief determinant of the former, must by no means be construed as indicating that the latter determination may be safely dispensed with. In the examination of certain distinctly pathologic salivas the writer has found lactic acid present which led to a fairly high hydrogen ion concentration and consequent low pH of the saliva even after prolonged and vigorous aeration, in the course of which comparatively little carbon dioxide was given off. This contingency may be seldom met with, but its possibility renders it absolutely necessary that the saliva be subjected to aeration or other adequate method of determination of carbon dioxide content in connection with the determination of the hydrogen ion concentration of the saliva, if the latter is to be of any diagnostic value whatever.

2. *Do psychopathic stammerers show a characteristically low hydrogen ion concentration and carbon dioxide content of the mixed saliva, and may these salivary biochemical characteristics be employed as indices of chronic emotional excitement?*

[31]See Note 19 *supra.*

Table 3. The Hydrogen Ion Concentration of the Mixed Saliva of Sub-breathing Stammerers, in terms of Relative Frequency

Hydrogen Ion concentration of the mixed saliva	Relative frequency
pH	%
5.4 minus[32]	2.0
5.40	1.0
5.45	1.5
5.50	1.5
5.55	2.0
5.60	1.5
5.65	0.5
5.70	2.0
5.75	4.0
5.80	4.5
5.85	7.0
5.90	7.5
5.95	9.0
6.00	10.0
6.05	8.5
6.10	7.5
6.15	7.0
6.20	6.5
6.25	5.0
6.30	3.5
6.35	2.5
6.40	2.0
6.45	0.5
6.50	1.0
6.55	0.5
6.60	1.5

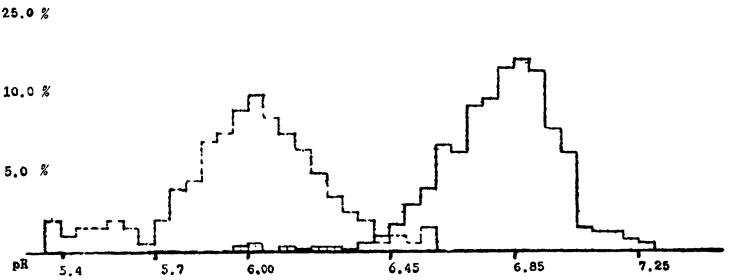

CHART 1. The hydrogen ion concentration of the mixed saliva of sub-breathing stammerers and of normal individuals
Abscissa: Hydrogen ion concentration in terms of pH
Ordinate: Relative frequency in terms of per cent
———— indicates normal individuals
— — — — — indicates sub-breathing stammerers

[32]Inasmuch as the lower limit of accuracy of the indicator employed is pH 5.40, specimens showing a virage indicating a lower pH are reported imply as "pH 5.40 minus."

Table 4. The Hydrogen Ion Concentration of the Mixed Saliva of Psychopathic Stammerers, in Terms of Relative Frequency

Hydrogen ion concentration of the mixed saliva	Relative frequency
pH	%
6.90	2.0
6.95	2.0
7.00	---
7.05	---
7.10	---
7.15	2.0
7.20	4.0
7.25	---
7.30	4.0
7.35	2.0
7.40	4.0
7.45	6.0
7.50	6.0
7.55	10.0
7.60	14.0
7.65	12.0
7.70	10.0
7.75	8.0
7.80	6.0
7.85	2.0
7.90	4.0
7.95	---
8.00	2.0

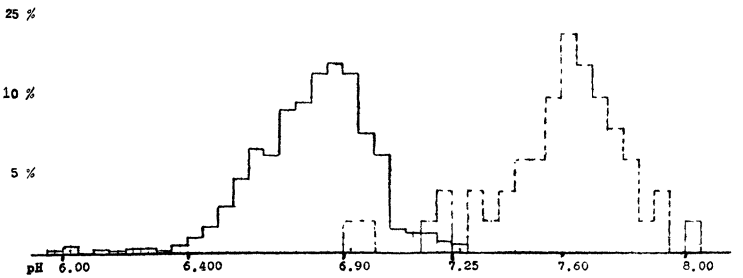

CHART 2. The Hydrogen Ion Concentration of the Mixed Saliva of Normal Individuals and of Psychopathic Stammerers

Abscissa: Hydrogen ion concentration in terms of pH
Ordinate: Relative frequency in terms of per cent
———————— indicates normal individuals
— — — — — — indicates psychopathic stammerers

A series of determinations similar to those just described as having been made on sub-breathers was applied to 10 distinctly psychopathic stammerers, embracing 50 determinations distributed thus: 2 determinations each on 2 subjects, and 6 determinations each on 8 subjects. The results are presented in Table 4 and in Chart 2.

Table 4 and the accompanying Chart 2 show clearly that the hyperexcitable psychopathic stammerers examined had a much lower hydrogen ion concentration and carbon dioxide content of the mixed saliva than have normal healthy individuals. With the exception of one psychopathic sub-breather, whose salivary pH was on one occasion 6.90 and on another 6.95, every specimen examined was between pH 7.15 and 8.00. The mean, mode, and median were respectively 7.70, 7.55 to 7.75, and 7.60. Eighty per cent of the specimens were above pH 7.25 and below 7.95. It appears evident, therefore, that the psychopathic stammerer is in general so hyperexcitable that his emotional balance, such as it is, is upset by the mere act of furnishing a specimen of saliva, or that he is in a state of chronic excitement. Probably both conclusions are true. For whether apparently upset or not, the psychopath's salivary pH was almost invariably far above the normal limits, and even exceeding those found obtaining in normal individuals when intensely excited. That the majority of these subjects were abnormally perturbed by the mere presentation to them of the saliva collection tube was indicated by their turning away their heads, flushing, etc. This behavior was in marked contrast to the usually more or less dull and sodden "spitting" of the typical sub-breather. These findings, then, would also indicate that a persistently high salivary pH is an index of more or less chronic emotional excitement.

3. *Do hyper-excitable subjects show evidence of their excitement by concomitant decrease in hydrogen ion concentration and carbon dioxide content of the mixed saliva, and may these salivary biochemical characteristics be employed as indices of transient emotional excitement?*

The sub-breathing and psychopathic stammerers employed in the two preceding investigations were examined in the following manner. Each subject, after the ejection of a mouthful of saliva (the pH and carbon dioxide content of which were determined as before described), was excited as far as possible by verbal goading of a stereotyped form. This goading was not such as would be offensive to a normal individual, but was quite enough to disturb a hyper-excitable or psychopathic subject. It was continued for 5 min., when the collection tube was again presented to the subject, and he was directed to eject into it all of the saliva now in his mouth. (In four in-

TABLE 5. The Effect of Verbal Goading upon the Ability to Speak and the Hydrogen Ion Concentration of the Mixed Saliva of Sub-breathing Stammerers

No.	Before goading: Salivary pH	Ability to speak within 1′	Ability to speak within 2′	Before goading: Ability to speak within 1′	Before goading: Ability to speak within 2′	After 5 min. goading: Salivary pH	Diff. from initial pH	After 5 min. goading: Ability to speak within 1′	After 5 min. goading: Ability to speak within 2′	After 10 min. rest period: Salivary pH	Diff. from pH during goading	Diff. from initial pH
1	5.40	—	+	—	+	5.40	0.00	—	+	5.40	0.00	0.00
2	5.50	—	+	—	+	5.55	+ 0.05	—	+	5.55	0.00	+ 0.05
3	5.60	—	+	—	—	5.75	+ 0.15	—	+	5.65	— 0.10	+ 0.05
4	5.65	+		+		5.60	— 0.05	+		5.60	0.00	— 0.05
5	5.75	+		—	+	5.80	+ 0.05	—	+	5.70	— 0.10	— 0.05
6	5.75	+		—	+	5.65	— 0.10	+		5.60	— 0.05	— 0.15
7	5.80	+		+		5.85	+ 0.05	+		5.85	0.00	+ 0.05
8	5.85	—	+	—	—	6.00	+ 0.15	+		5.80	— 0.20	— 0.05
9	5.85	+		+		5.85	0.00	—	+	5.85	0.00	0.00
10	5.85	—	+	—	+	5.90	+ 0.05	—	+	5.90	0.00	+ 0.05
11	5.90	—	—	—	+	6.00	+ 0.10	—	+	5.90	— 0.10	0.00
12	5.90	—	+	—	+	5.90	0.00	+		5.90	0.00	0.00
13	5.90	+		+		5.95	+ 0.05	+		5.95	0.00	+ 0.05
14	5.90	+		+		5.90	0.00	—	+	5.85	— 0.05	— 0.05
15	5.95	+		—	—	6.15	+ 0.20	—	+	5.95	— 0.20	0.00
16	6.00	—	+	—	—	6.20	+ 0.20	—	+	6.05	— 0.15	+ 0.05
17	6.00	+		+		6.00	0.00	—	+	6.00	0.00	0.00
18	6.00	+		+		6.05	+ 0.05	+		6.05	0.00	+ 0.05
19	6.20	—	+	—	+	6.20	0.00	—	+	6.20	0.00	0.00
20	6.20	—	+	—	—	6.45	+ 0.25	—	+	6.25	— 0.20	+ 0.05
21	6.25	—	+	—	+	6.20	— 0.05	+		6.20	0.00	— 0.05
22	6.30	—	+	—	+	6.30	0.00	+		6.30	0.00	0.00
23	6.30	+		+		6.25	— 0.05	+		6.25	0.00	— 0.05
24	6.35	+		+		6.40	+ 0.05	—	+	6.35	— 0.05	0.00
25	6.40	+		—	+	6.50	+ 0.10	+		6.35	— 0.15	— 0.05
26	6.50	—	+	+		6.50	0.00	+		6.50	0.00	0.00
27	6.60	—	+	—	—	6.90	+ 0.30	+		6.50	— 0.40	— 0.10
Total	161.95					Total 163.20				Total 163.25		
	27)161.95					27)163.20				27)163.25		
average	6.00					average 6.04				average 6.05		

stances, when the mouth was dry, the subject was urged to expectorate as soon as possible, and the required 1 cubic cm. was forthcoming within 1.5 min.) The subject was then immediately ordered to say "yes, sir," and his ability to say it within 1 or 2 min. was carefully noted, as being largely indicative of the extent of his emotional disturbance. The saliva ejected immediately after the goading was examined in the same manner as the former specimen, and the subject was allowed a 10 min. period of quietude during which to calm down. Then, after a few remarks, calculated to prevent excitement as far as possible, he was again required to say "yes, sir," the time consumed being again noted, and his saliva was again examined as before.

The experiment was conducted on 37 subjects, of whom 27 were decided sub-breathers and 10 unquestionably psychopathic. In no instance do the data presented include more than one investigation of the same individual. For it is obvious that, having once experienced the goading and ascertained its purpose, subsequent repetition of the experiment upon a subject would not have had an effect comparable with that upon one not thus initiated.[33] The results obtained are presented interpretatively in Tables 5 and 6.

SUMMARY OF TABLE 5. Sub-breathers.

Average initial hydrogen ion concentration of the mixed saliva = pH 6.00

After 5 min. verbal goading:

Average hydrogen ion concentration of the mixed saliva = 6.04.

14.8% of the subjects showed a slight decrease in salivary pH, ranging from 0.05 to 0.10, and averaging 0.06.

29.6% of the subjects showed no change in salivary pH.

55.6% showed a slight increase, ranging from 0.05 to 0.30, and averaging 0.12.

After 10 min. period of quietude:

Average hydrogen ion concentration of the mixed saliva = 6.05.

Difference from salivary pH immediately after goading:

55.6% of the subjects showed no change in salivary pH.

44.4% of the subjects showed a slight decrease, ranging from 0.05 to 0.40, and averaging 0.15.

Average change in salivary pH for the group was minus 0.065.

Difference from initial salivary pH:

33.33% of the subjects showed a slight decrease, ranging from 0.05 to 0.15, and averaging 0.067.

37.04% of the subjects showed no change.

29.63% of the subjects showed a slight increase, which in every instance was 0.05.

Average change in salivary pH for the group was minus 0.007.

[33] In a subsequent investigation we expect to make a series of similar examinations of the degree of emotional stability or instability, expressed in terms of change of salivary pH due to an emotionalizing stimulus comparable to the initial verbal goading, of the same subjects when they are ready for discharge as cured from the Clinic, to determine the stabilizing value of the corrective treatment they have received.

TABLE 6. The Effect of Verbal Goading upon the Ability to Speak and the Hydrogen Ion Concentration of the Mixed Saliva of Psychopathic Stammerers

	Before goading				After 5 min. goading				After 10 min. rest period			
No.	Salivary pH	Ability to speak within 1′	2′	Ability to speak within 1′ 2′	Salivary pH	Diff. from initial salivary pH	Ability to speak within 1′	2′	Salivary pH	Diff. from pH during goading	Diff. from initial salivary pH	
1	6.80	—	+	— —	7.15	+ 0.35	—	+	6.90	— 0.25	+	0.10
2	7.30	—	—	— —	8.10	+ 0.80	—	—	7.80	— 0.30	+	0.50
3	7.50	+		— +	7.70	+ 0.20	—	+	7.55	— 0.15	+	0.05
4	7.50	—	+	— —	8.00	+ 0.50	—	+	7.60	— 0.40	+	0.10
5	7.65	—	+	— —	8.00	+ 0.35	—	+	7.70	— 0.30	+	0.05
6	7.65	+		— +	7.75	+ 0.10	+		7.60	— 0.15	—	0.05
7	7.70	—	+	— —	8.10	+ 0.40	—	+	7.60	— 0.50	—	0.10
8	7.50	—	+	— —	7.95	+ 0.45	—	—	7.80	— 0.15	+	0.30
9	7.35	—	+	— —	7.65	+ 0.30	+		7.35	— 0.30	+	0.00
10	7.40	+		— —	7.95	+ 0.55	—	—	7.75	— 0.20	+	0.35
Total	74.35				Total 78.39				Total 75.62			
	10)74.35				10)78.39				10)75.62			
Average	7.44				average 7.84				average 7.56			

SUMMARY OF TABLE 6. Psychopaths.

Average initial hydrogen ion concentration of the mixed saliva = 7.44.

After 5 min. verbal goading:

Average hydrogen ion concentration of the mixed saliva = 7.84.

100% of the subjects showed an increase in salivary pH, ranging from 0.10 to 0.80, and averaging 0.40.

After 10 min. period of quietude:

Average hydrogen ion concentration of the mixed saliva = 7.56.

Difference from salivary pH immediately after goading:

100% of the subjects showed a decided decrease, ranging from 0.15 to 0.50, with an average of 0.27.

Difference from initial salivary pH:

20% of the subjects showed a slight decrease, averaging 0.075.

10% of the subjects showed the same salivary pH as before the goading.

70% of the subjects showed a higher salivary pH than before the goading, the increase ranging from 0.05 to 0.50, and averaging 0.21.

Average change in pH for the group = plus 0.13.

(*a*) The first point that we notice in considering the data presented in Tables 5 and 6 is that the average initial salivary pH of the sub-breathers is 6.0 and that of the psychopaths 7.4, indicating the same fact made evident in Tables 3 and 4, *i. e.*, that the sub-breathers show a salivary pH in general considerably below, and the psychopaths display one considerably above, that of the normal individual (approximately 6.8).

(*b*) The next striking differentiation to be noted is that as a group the sub-breathers showed practically no change in salivary pH as the result of the verbal goading. (The average change for the group was only + 0.057.) A change of less than 0.10 in salivary pH may be regarded as negligible. The few subjects who did show noticeable change—especially nos. 20 and 27, whose salivary pH increased respectively 0.25 and 0.30—displayed hyper-excitability and more or less decided neurotic tendencies to such a degree that at the outset it was difficult to decide whether to list them with the sub-breathers or the psychopaths. It will be noted that they were both totally unable to say "yes, sir" within 2 min. after the cessation of the goading. Subjects 15 and 16, showing an increase in salivary pH of 0.20, were not psychopathic, but were hyper-excitable. Both displayed a somewhat exaggerated patellar reflex (as did also nos. 20 and 27, to an even more marked degree). Neither was able to say "yes, sir" within the stipulated 2 min. The sudden opening of a door behind him in the office where he was seated, presumably comfortably, for the collection of a specimen of saliva, caused no. 16 to start perceptibly.

The psychopaths in general showed a pronounced increase in salivary pH following the verbal goading. In every instance there was an increase ranging from 0.10 to 0.80, with mode and

median approximately 0.4 and a mean of exactly 0.4. That a high degree of excitement resulted from the goading was amply demonstrated by the behavior of the psychopaths. All except nos. 3 and 6 (who showed an increase in salivary pH respectively of only 0.20 and 0.10) were unable to respond to the command to speak with more than voiceless twitching of the lips for more than 2 min. No. 6 forced out the required "yes, sir" in 1′ 22″ accompanying it with a determined shake of the head.

It is thus quite evident that, both as regards the psychopaths and the sub-breathers, emotional disturbance and increase in salivary pH went *pari passu.*

(*c*) The third differentiation brought out by this investigation was with regard to decrease in salivary pH upon subsidence of the emotional excitement. After the 10 min. period of quietude, all of the sub-breathers succeeded in enunciating "yes, sir" within the required 2 mins., with the exception of no. 27, who took 2′ 28″. Nos. 20 and 26 succeeded in the test barely within 2 min. Each one of the three subjects had displayed under goading a rather high degree of hyper-excitability, indicated by marked rise in salivary pH and concomitant decrease in carbon dioxide content of the saliva. In connection with this ability to speak after the period of quietude, noted in the majority of the sub-breathers, it may be remarked that the final salivary pH of each of them, except no. 27, was practically identical with his initial salivary pH.

The psychopaths, however, varied greatly among themselves as to their ability to pronounce "yes, sir" after the 10 min. period of quietude. It required 4′ 18″ for no. 2 to get it out, which might have been anticipated from the fact that his final salivary pH was 0.5 higher than his initial one. Subject 6 responded with the test words almost immediately when requested to do so. Under goading his salivary pH had increased only 0.10, and after the rest period it was practically the same as at the beginning of the examination. Nos. 8 and 10 were unable to speak within the 2 min. limit. The salivary pH of each at this time was still respectively 0.30 and 0.35 above the initial pH. No. 9 required 59″ to get out the test words. The others required more than 1′ and less than 2′. It is evident, therefore, that the psychopathic stammerers not only become more easily excited than do the sub-breathers, but that in the main their excitement subsides more slowly,—or is reestablished much more readily. For it is difficult to say definitely whether the psychopaths, whose final salivary pH was above their initial pH, were *still* excited or *again* excited.

It would appear from these tests that the hydrogen ion concentration of the mixed saliva, when its fluctuations are due to variations in the quantity of carbon dioxide present, as was the

case in every one of the foregoing analyses, may be employed to determine the relative excitability of an individual.

Application.—The tests already described were applied to a group of 7 stammerers who showed little if any anatomical indication of defective breathing and who were not psychopathic. The results are presented in Table 7.

TABLE 7. Examination of Seven Unclassified Stammerers

	Before goading				After 5 min. goading				After 10 min. rest period			
No.	Salivary pH	Ability to speak within 1′	Ability to speak within 2′		Salivary pH	Diff. from initial PH	Ability to speak within 1′	Ability to speak within 2′	Salivary pH	Diff. from pH under goading	Diff. from initial pH
1	6.10	+	+		6.15	+ 0.05	+		6.15	0.00	0.05
2	6.30	—	+	+	6.25	— 0.05	+		6.25	0.00	—0.05
3	6.85	+	+		6.90	+ 0.05	+		6.85	— 0.05	0.00
4	6.95	+	+		6.90	— 0.05	+		6.95	+ 0.05	0.00
5	6.95	—	—	—	7.35	+ 0.40	—	—	7.15	— 0.20	+0.20
6	7.00	—	+	+	7.30	+ 0.30	—	+	7.10	— 0.20	+0.10
7	7.35	—	+		7.65	+ 0.30	—	+	7.40	— 0.25	+0.05

Interpreting Table 7 in the light of the preceding findings we may diagnose nos. 1 and 2 as not hyper-excitable sub-breathers; nos. 3 and 4 as neither sub-breathers, psychopathic, nor hyper-excitable (no. 4 was, in fact, an old case about ready for dismissal from the Speech Clinic as Cured); nos. 5 and 6 as hyper-excitable; and no. 7 as hyper-excitable and probably more or less psychopathic.

SUMMARY

As a result of this research, involving about 1300 salivary analyses and psychological diagnostic judgments, what has been found?

First, as to stammerers. There is one group of stammerers, embracing 73.7 per cent of the stammerers examined in the general survey of those who applied for aid to the Speech Clinic of this University during the scholastic year of 1921-22, who may be denominated as sub-breathers and who have their organisms overloaded with carbon dioxide. As a consequence their mental faculties are dulled, they are always working in a "fatigued" condition, virtually under pressure. Until the carbon dioxide content of their blood has been reduced more nearly to normal limits it is practically hopeless for them to attempt to break any old habits or acquire any new ones, whether of speech or otherwise. Proper breathing exercises in the open air adapted to the individual's requirements should be of immense value in this connection.[34] A decrease in the carbohydrate content of the diet should also prove of benefit.

[34]A series of experiments is now in progress to determine the efficacy in freeing the system of excess carbon dioxide by means of certain specific breathing exercises.

Another, and considerably smaller group of stammerers are distinctly psychopathic,—somewhat less than 15.4% of those examined in the present research. These subjects are generally very hyper-excitable. They discharge a disproportionate amount of energy in response to an immediate stimulus, displaying no sense of proportion. A stimulus which would have very little effect upon a normal subject, and none at all upon a typically dulled sub-breather, upsets the "equilibrium" of a psychopath completely. They are practically hopeless subjects for remedial measures, so far as correction of their speech defect is concerned, unless their general psychopathic condition is first cured. For while they may respond with all their power to the stimulus of treatment, in the way of exercises, drill, etc., in the presence of the teacher, there is little if any apperceptive residuum left. Once out of sight of the Clinic, what they have there done and been told to do is speedily eradicated from their minds by fresh stimuli, to which they respond with the same disproportionate display of energy.

Obviously another type of stammerer may be both hyper-excitably psychopathic and a sub-breather. Such a subject in a hyper-excited condition might eject a saliva apparently normal as to pH, inasmuch as his sub-breathing habits would tend to keep his salivary pH low, while his hyper-excited condition would tend to raise it. Between the two contending factors, the salivary pH, at some given moment when the specimen is collected and the determination made, may be occupying a median position approximating that of a normal saliva. An adequate series of determinations, however, should show his predominant tendency, and the series of tests with and without verbal goading will serve to indicate his degree of excitability.

A fourth group of stammerers may not be dulled by defective breathing or other cause of overloading the system with carbon dioxide, resulting in chronic "fatigue" and concomitant lack of energy, nor may they be psychopathic. They may simply be hyper-excitable. Perhaps it is from this class that the psychoanalyst recruits his subjects.

In the light of our findings as to the metabolic etiology of stammering, we may sum up the therapeutic measures indicated by stating that the sub-breathers must be toned up and their systems freed from excessive carbon dioxide by a technique probably involving vigorous breathing exercises and a control of the diet, in addition to the regular drill; the hyper-excitables must be calmed down; and the psychopaths—sent first to a psychiatrist.

As to the hydrogen ion concentration of the mixed saliva in conjunction with determinations of the carbon dioxide content, the present research has found it useful as an index of

(1) the condition of an individual as to fatigue or energy at his disposal, and the breathing habits of the individual;

(2) the degree of emotional excitement under which the subject is laboring at the time of the determination—thus enabling the constantly excited psychopath to be readily detected; and

(3) the degree of excitability of an individual, by means of a series of determinations made before, during and after the application of a definite emotionalizing stimulus.

The question remains why the hydrogen ion concentration of the mixed saliva, due to the presence of carbon dioxide, is abnormally high in sub-breathers and fatigued individuals, and abnormally low in chronically excited psychopaths. And why in excitement does the salivary pH tend to rise in both normal and abnormal individuals? No dogmatic answer may be given. It would appear, however, that the explanation is somewhat as follows. As a result of either sub-breathing, muscular exertion, or excessive ingestion of carbohydrates, carbon dioxide accumulates in the blood and in the alveolar air in excess of the normal tension. The result is, *normally*, a certain degree of hyperpnoea to relieve the tension, for carbon dioxide is a specific stimulus of the respiratory center as are also lactic acid and other products of fatigue,[35] the teleology of the hyperpnoea being to expel enough carbon dioxide so that normal limits may again be reached. The consequence is that normally the carbon dioxide content of the alveolar air varies but little in an individual, an increase in carbon dioxide content of the blood resulting in augmented respiration rather than in accumulation of carbon dioxide in the alveolar air. There is, however, some increase in the latter, and, as we have found, the salivary hydrion concentration increases as the carbon dioxide content of the alveolar air increases, but to a greater degree. Consequently, a high hydrion concentration of the saliva, when due to carbon dioxide, indicates a high carbon dioxide content of the alveolar air, and therefore of the blood. A high carbon dioxide content in the blood manifests itself in fatigue, dullness, inertia.[36] This concomitant excitation of the respiratory center and dulling of the centers stimulating the individual to activity has probably developed ontogenetically because of its phylogenetic import. For when there is a great accumulation of carbon dioxide throughout the organism, further activity might endanger life, and the individual would probably keep going until he inadvertently committed suicide. But fatigue, inertia, dullness, lead him to a cessation of carbon dioxide producing effort, and meanwhile the stimulation of the respiratory center, as noted, normally leads to expulsion of the excess carbon dioxide, and a return to normal conditions of the blood and system in general. It is possible in the case of the most pronounced sub-breathing stammerers, or other individuals with markedly high salivary hydrion concentrations due to the presence of carbon dioxide in the saliva, that in addition to, or in the absence of, pernicious breathing, working, or dietary habits *per se*, there may be a lack of sensitivity of the respiratory center, so that the carbon dioxide may accumulate in the blood leading to a chronic fatigue, or even somewhat of a mental numbness, without the normally concomitant hyperpnoea to rid the system of the excess carbon dioxide. In this event, also, very vigorous breathing, deliberately and regularly practised (a sort of artificial hyperpnoea) may be of great remedial value.

[35]Cf. Robertson, T. B., Principles of Biochemistry. N. Y. and Phila., 1920. Pp. 364-368.

[36]For the toxicology of carbon dioxide see Kobert, R., Lehrbuch der Intoxikationen, II. Stuttgart, 1906. Section on Kohlensäure, pp. 1120-23.

With regard to the problem why the psychopaths examined showed constantly such abnormally low hydrogen ion concentration of the mixed saliva (and consequent high pH), we must again avoid dogmatic assertion. Their practically chronic emotional excitement, whether or not displayed by overt acts, suggests that the same physiological etiology obtains as in the case of any subjects, normal or abnormal when their salivary pH increases during emotional stress. This may be attributed largely to the hyperpnoea, amounting in high degrees of excitement to a veritable dyspnoea, which rids the alveolar air (and consequently the blood) of a large part of its carbon dioxide content. In psychopathic subjects the respiratory center *may* be abnormally sensitive to relatively small quantities of carbon dioxide in the blood, or there *may* be abnormal activity of the adrenals resulting in excessive quantities of adrenin in the blood, causing a more or less chronic dilatation of the bronchioles and thereby diminished carbon dioxide tension of the blood and alveolar air. In either or both cases the result would be decreased carbon dioxide content of the mixed saliva and consequent lower hydrogen ion concentration, indicated by increased salivary pH.

In normal individuals the functioning of the adrenals in times of emotional stress is probably a prime factor in the stimulation of the respiratory center and dilatation of the bronchioles. In other words, in emotional excitement the functioning of the adrenals prepares the organism for flight or fight by ridding the system to a greater degree than usual of carbon dioxide, and preparing it for the speedy removal of the excessive quantities of carbon dioxide which would result from intense exertion. The teleology of the function is the prevention or postponement of fatigue and exhaustion. When the prepared-for exertion does not follow, the carbon dioxide content of the blood and of the alveolar air probably remains for some time below the normal limits, with the result that there is an even more greatly diminished carbonic acid content and consequently lowered hydrogen ion concentration of the mixed saliva, indicated by a high salivary pH.